Corrosion and its effect on wire rope used in underground coal mines

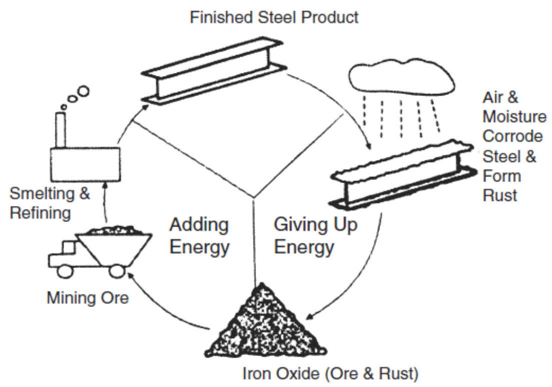
R. P. Singh, Mousumi Mallick, M. K. Verma

Abstract— **Industries in India play an important role in the economic growth of country. These industries face challenging conditions in effective corrosion estimation, prevention and control. The corrosion cost in any developing country is predicted by 5% of the GDP which is significant to all countries. In this paper brief information about corrosion and its types has been given. The effects of corrosion in our daily lives are both direct where corrosion affects the useful service lives of our possessions, and indirect where in producers and suppliers of goods and services incur corrosion costs, which they pass on to consumers. Corrosion poses a serious threat to mining industries as well. Wire rope which is an intricate device made up of a number of precise moving parts used in underground mines. The amount of corroded metal is a function of the surface which oxygen can attack. Steel wire ropes have an exposed surface about 16 times larger than a steel bar of the same diameter and will therefore corrode correspondingly faster. Here in this paper, how corrosion can seriously shorten wire rope life, both by metal loss and by formation of corrosion pits in the wires has been described. Static ropes (suspension ropes or rope sections lying over a saddle or an equalizer sheave) are more likely to corrode faster than running ropes/ winding ropes. This has been illustrated with failure analysis of two different types of wire ropes used in coal mines, one guide rope which is static in nature and one winding rope which is a moving rope. From the two case studies it is found that the static guide rope used in coal mines has been failed due to excessive corrosion resulted in high reduction in diameter.**

Index Terms— **Corrosion, corrosion on wire rope, types of corrosion, wire rope, wire rope failure.**

I. Introduction

Corrosion can be defined as a chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties. Corrosion is a natural process. Just like water flows to the lowest level, all natural processes tend toward the lowest possible energy states. Thus, for example, iron and steel have a natural tendency to combine with other chemical elements to return to their lowest energy states. In order to return to lower energy states, iron and steel frequently combine with oxygen and water, both of which are present in most natural environments, to form hydrated iron oxides (rust), similar in chemical composition to the original iron ore. Figure 1 illustrates the corrosion life cycle of a steel product [1].



Industries in India play an important role in the economic growth of country. These industries face challenging conditions in effective corrosion estimation, prevention and control. The corrosion cost in any developing country is predicted by 5% of the GDP which is significant to all countries. For India the cost of corrosion is estimated to be 36,000 Crores INR in 2008. This is about half of our defence budget and perhaps double of our total annual expenses on education. The table 1 [2] below summarizes the total cost of corrosion of various nations and percentage of gross domestic product (GNP) of the respective nations. It is clear from the table that the cost of corrosion varies from 1.5 to 5.2 percent of GNP [3].

Table I: Cost of corrosion for different countries

Country	Total Annual Corrosion cost (US$)
USSR	6.7 billion
West Germany	6 billion
Finland	47-62 million
Sweden	58 million
UK	3.2 billion
India	320 million
Australia	470 million
Japan	9.67 billion

II. Types of Corrosion:

Corrosion occurs in several widely differing forms. Classification is usually based on one of three factors [1]:

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- Nature of the corrodent: Corrosion can be classified as "wet" or "dry." A liquid or moisture is necessary for the former and dry corrosion usually involves reaction with high-temperature gases.
- Mechanism of corrosion: This involves either electrochemical or direct chemical reactions.
- Appearance of the corroded metal: Corrosion is either uniform and the metal corrodes at the same rate over the entire surface, or it is localized, in which case only small areas are affected.

Eight forms of wet (or aqueous) corrosion can be identified based on appearance of the corroded metal. These are:

- Uniform or general corrosion
- Pitting corrosion
- Crevice corrosion, including corrosion under tubercles or deposits, filiform corrosion, and poultice corrosion
- Galvanic corrosion
- Erosion-corrosion, including cavitation erosion and fretting corrosion
- Intergranular corrosion, including sensitization and exfoliation
- Dealloying, including dezincification and graphitic corrosion

Environmentally assisted cracking, including stress-corrosion cracking, corrosion fatigue, and hydrogen damage.

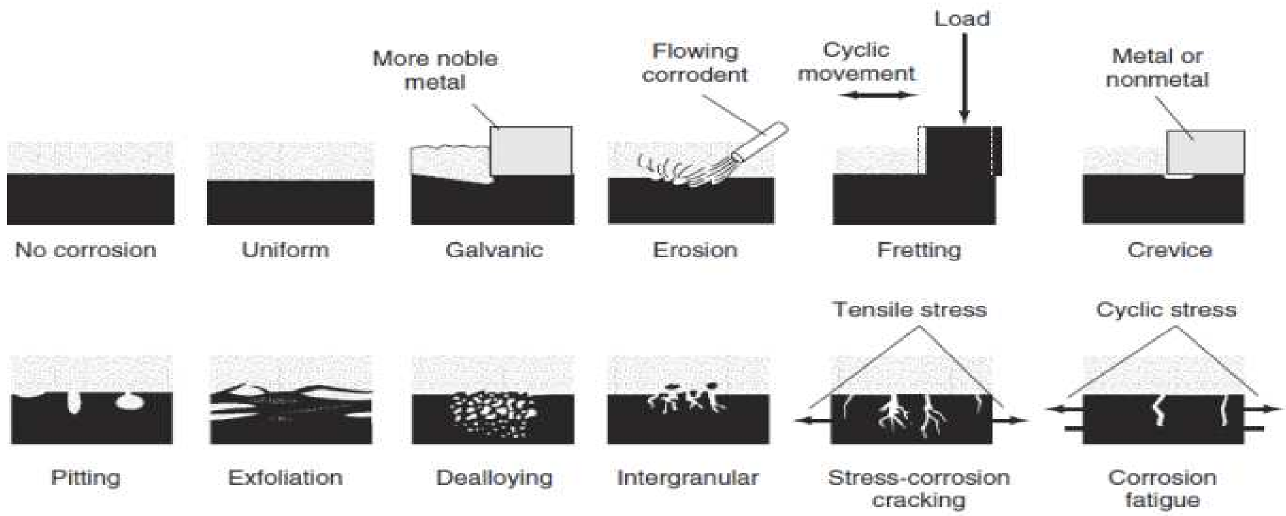

Figure 2: Common forms of corrosion

III. CONSEQUENCES OF CORROSION:

The effects of corrosion in our daily lives are both direct and indirect, in that corrosion affects the useful service lives of our possessions, and indirect, in that producers and suppliers of goods and services incur corrosion costs, which they pass on to consumers.

Most dangerous of all is corrosion that occurs in major industrial plants, such as electrical power plants or chemical processing plants. Plant shutdowns can and do occur as a result of corrosion. This is just one of its many direct and indirect consequences [1] which may Cuse economic and social impacts are as under:

Economic causes:

- Replacement of corroded equipment
- Overdesign to allow for corrosion
- Needs preventive maintenance, for example, painting/ coating etc.
- Shutdown of equipment due to corrosion failure
- Contamination of a product
- Loss of efficiency—such as when overdesign and corrosion products decrease the heat-transfer rate in heat exchangers
- Loss of valuable product packed in a corroded container
- Inability to use otherwise desirable materials
- Damage of equipment adjacent to that in which corrosion failure occurs

Social causes:

- Safety, for example, sudden failure can cause fire, explosion, release of toxic product, and construction collapse
- Health, for example, pollution due to escaping product from corroded equipment or due to a corrosion product itself
- Depletion of natural resources, including metals and the fuels used to manufacture them
- Appearance as when corroded material is unpleasing to the eye

IV. WIRE ROPE USED IN MINES:

Wire rope is an intricate device made up of a number of precise moving parts [4] used in underground mines. Wire rope is composed of three parts: wires, strands, and core (Figure. 3). The basic unit is the wire.

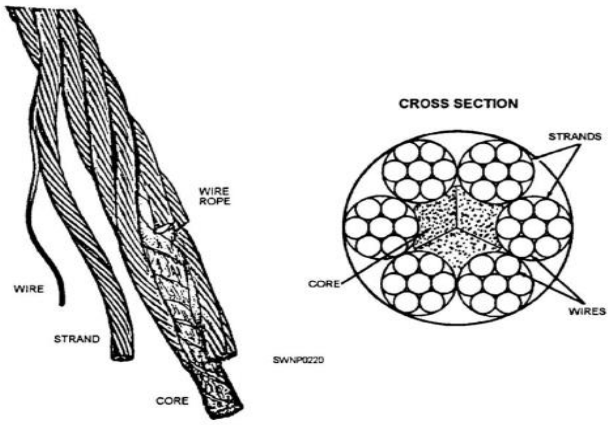

Figure 3: Wire Rope Structure

During operation of a wire rope the main strands change position longitudinally with respect to each other and within the strands the individual wires do likewise [4]. These relative motions tend to distribute and equalize the combined stresses among the strands and wires. As a result the rope becomes flexible. This free relative motion of the wires and the strands is facilitated by appropriate internal lubrication. Lubrication helps to combat the frictional forces which oppose the movements among the strand and the wire.

The core of the wire rope plays a vital role by providing a foundation for the strands. This foundation maintains the proper lateral position of the strands and permits their relative longitudinal motion in adjusting the distribution of the applied stresses. The more commonly used cores are of three types. They are:

i. Independent wire rope core (IWRC)
ii. Wire strand core (SC or WSC)
iii. Fibre core

Independent wire rope core (IWRC):
An independent wire rope core is a separate wire rope over which the main strands of the rope are laid. This core strengthens the rope, provides support against crushing, and supplies maximum resistance to heat. Independent wire rope core find general application on excavating and earth moving equipment, logging winches and on mobile crane equipment [5].

Wire strand core (SC or WSC):
A wire strand core resists more heat than a fibre core and also adds about 15 percent to the strength of the rope; however, the wire strand core makes the wire rope less flexible than a fibre core.

Fibre core wire rope:
The main purpose of a fibre core in a wire rope is to provide resilient foundation for the strands in the rope structure and to serve as a source of lubrication. Fibre cores are lubricated suitably to

- retard deterioration of the core fibres in service
- maintain pliability and prevent brittleness of the core fibres
- minimise internal friction and wear between core strands and fibres
- provide lubrication for the inside of rope strands

Fibre cores are used for ropes that are not subjected to heavy loads and where flexibility in handling is required. Fibre Cores are not used where wire rope is subjected to heavy load, prolonged exposure to weather and heavy crushing loads on small drums and sheaves.

V. Effect of Wear and Corrosion on Wire Ropes:

Corrosion can seriously shorten wire rope life, both by metal loss and by formation of corrosion pits in the wires. These pits act as stress-concentration points in the wires in much the same manner as do nicks. Pitting, erosion, and surface effects of many different types can all result in corrosion damage.
The amount of corroded metal is a function of the surface which oxygen can attack. Steel wire ropes have an exposed surface about 16 times larger than a steel bar of the same diameter and will therefore corrode correspondingly faster.
Wear and corrosion are characterized by a reduction in the cross section of the rope. If external or internal wear in steel wire ropes is in general uniform, corrosion is local and often overlaps to other anomalies.
Wear is classified into external or internal depending on whether it is on the outside of the rope or inside [6]. Internal wear is due to the contact and movement which occurs between wires. In the field the extent of wear of a wire rope is normally measured as a reduction in rope diameter. However, since the rope is not a rigid body, a reduction in rope diameter can be a summation of wear and other factors such as collapse of the core. In the case of abrasive wear, true external wear of the rope can be assessed by measuring either the loss in diameter of the outer wires, stated as a loss in their depth, or by measuring the width of the flats formed on the outer wires by wear. The former requires prising open the outer wires which can be difficult. The later is convenient to measure in practice but care must be taken to ensure that the measurement is accurate.
Abrasive wear is also accelerated under such conditions. Wire and strand movement is restricted. This increases the risk of failure by bending fatigue. The reduction of wire area due to corrosion will lead to failure under tensile loads. Corroded steel wire rope will lose its strength and flexibility. Corroded wire surfaces will form fatigue cracks much faster than protected surfaces. If high local stresses help propagate these cracks, the mechanism is called stress corrosion. Different forms of wear have been depicted in figure 4.

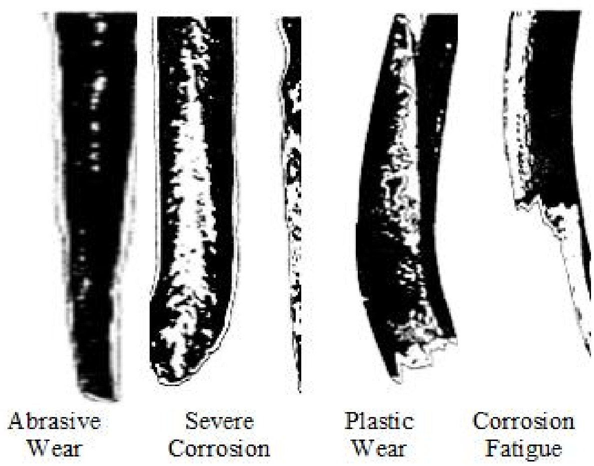

Figure 4: Different forms of wear

The amount of corrosion can be reduced by reducing the exposed surface. This can be done by galvanizing the rope wires. A steel core can also be protected by a plastic coating. An internal and external lubrication will also reduce or prevent corrosion. Steel expands when it corrodes. Therefore, sometimes an increase in rope diameter over time might be an indication that the rope is corroding internally. Static ropes (suspension ropes or rope sections lying over a saddle or an equalizer sheave) are more likely to corrode faster than running ropes/ winding ropes. This has been illustrated with failure analysis of two different types of wire ropes one guide rope which is static in nature and one winding rope which is a moving rope.

VI. CASE STUDY – I:

Failure analysis of a guide rope used in coal mines:

A. Sample Description:

Failed samples from 10/12 pits of KB Colliery have been received. The guide rope samples of 32mm diameter and six over one (6/1) construction have come for investigating the causes of failures. Three samples of failed guide rope of were taken from three different position of the guide rope [7].

1. One broken guide rope sample
2. One guide rope sample from top side broken portion
3. One guide rope sample from bottom side of the broken portioin

   The photoes of the samples are given in Figure 5.

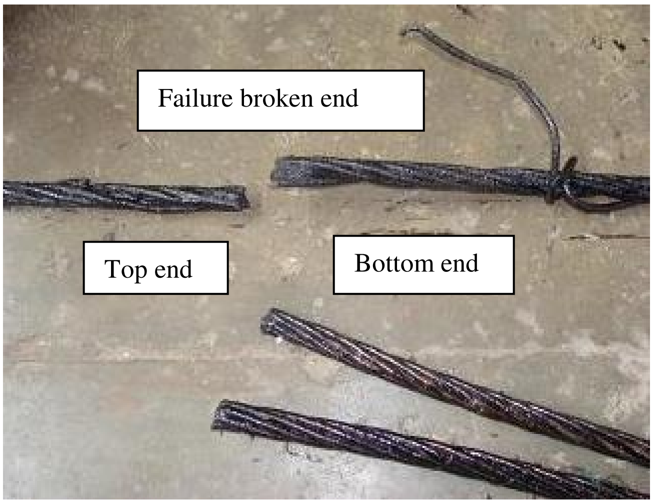

Figure 5: Broken guide rope sample

The following examinations were carried out to assess the exact causes of failure of supplied guide rope.

B. Visual Examination:

Visual examination revealed that the top end and bottom end portions of the failed guide rope was physically in good condition while in the broken failed portion out of seven wires, one wire have been broken out (Figure 5 & 6). After cleaning, the broken portion of the guide rope was found to have heavy wear and pittings (Figure 7).

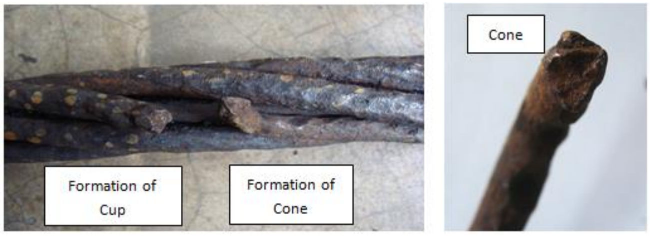

Figure 6: After cleaning of failure broken end

Figure-7: Wear, corrosion & pittings in one wire

C. Examination of wear & corrosion:

1) Broken end of the guide rope:
The un-galvanized round steel guide rope wire sample on physical examination revealed abrasive wear, helical indentation marks, nicking and severe corrosion pittings on the surface of the wire.

Max. Percentage reduction in diameter: 57.44%

Top end of the broken guide rope:

The un-galvanized round steel guide rope wire sample on physical examination revealed abrasive wear, helical indentation marks and corrosion pittings on the surface of the wire.

Max. Percentage reduction in diameter: 6.2%

2) Bottom end of the broken guide rope:
The un-galvanized round steel guide rope wire sample on physical examination revealed abrasive wear, helical indentation marks and corrosion pittings on the surface of the wire.

Max. Percentage reduction in diameter: 7.0%

D. Lubrication content in failed guide rope:

1) Broken end:
The lubrication condition of the given broken sample has been examined and calculated on the basis of rope mass as per IS: 3623-1978 and found below its critical passing value.

Top end & bottom end of the broken guide rope:

The lubrication condition of the given top end & bottom end sample was examined and found satisfactory.

E. Micro-examination:

1) Broken end of the guide rope:
The failed broken sample after cutting, grinding and polishing was examined under the microscope in an un-etched condition. The sample revealed no harmful inclusion as per IS: 4163-1982.
After etching in 2% nital solution the transverse and longitudinal section of the guide rope wire revealed normalized structure in a matrix of ferrite grains with

intermittent fine pearlite in the grain boundary (Figure 8a) typical to normalized low carbon steel. The structure of the failed broken end sample revealed elongated grains (Figure 8b) and corrosion pittings (Figure 8c) in the longitudinal section of the wire surface.

Visual Magnification 400X & 100X;
Micro photograph 2X180 Magnification

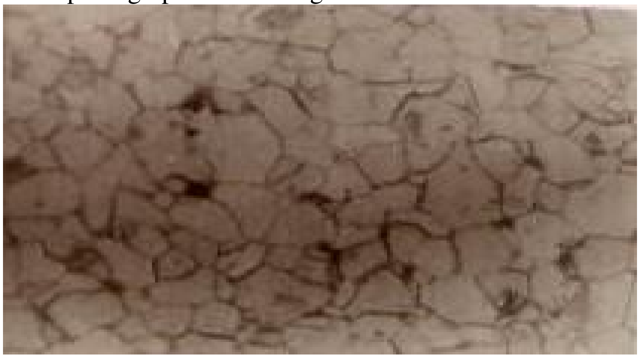

Figure 8a: Normalized structure 400X

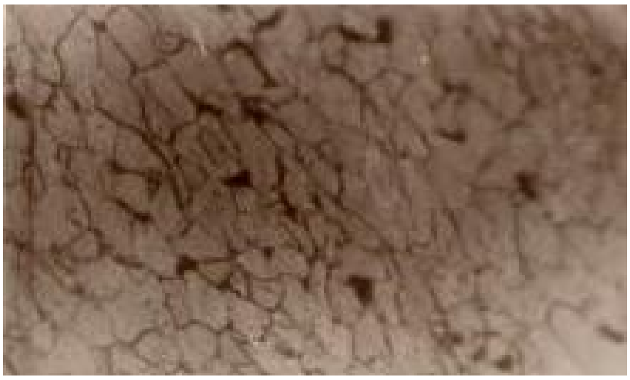

Figure 8b: Elongated grains 400X

Figure 8c: Corrosion pittings in longitudinal section 100X

Top end:

The top end of the sample after cutting, grinding and polishing was examined under the microscope in an un-etched condition. The sample revealed no harmful inclusion as per IS: 4163-1982.

After etching in 2% nital solution the sample revealed normalized structure with uniform distribution of fine pearlite in ferrite matrix (Figure. 9a) and corrosion pittings along the grain (Figure 9b,9c,9d) of low carbon steel on the surface of the wire both in transverse section and longitudinal section.

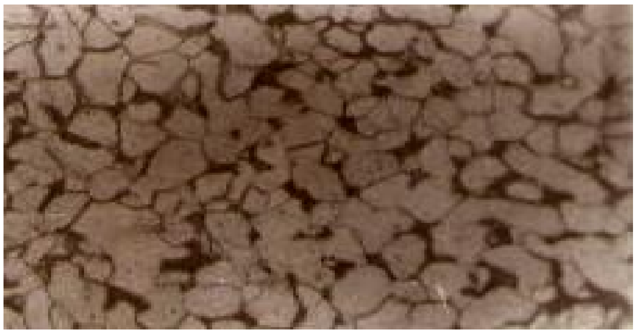

Figure 9a: Normalized structure 400X

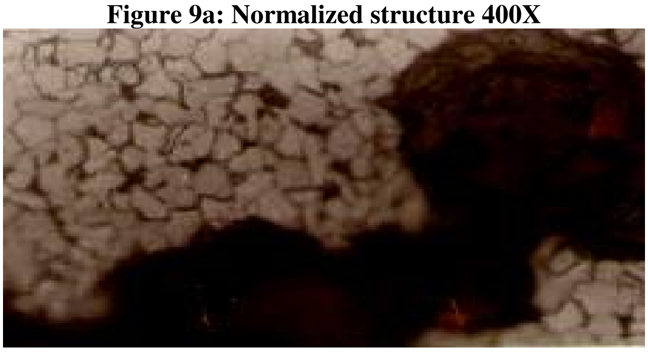

Figure 9b: Corrosion pittings 400X

Figure 9c: Corrosion pittings 400X

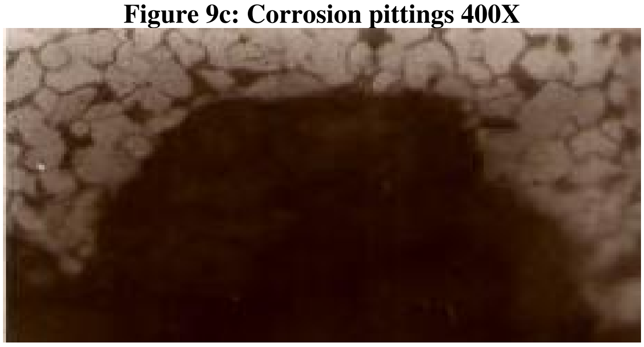

Figure 9d: Corrosion pittings 400X

Bottom end:

The bottom end sample after cutting, grinding and polishing was examined under the microscope in an un-etched condition. The sample revealed no harmful inclusion as per IS: 4163-1982.

After etching in 2% nital solution the sample revealed same normalized structure of low carbon steel with fine pearlite in the grain boundary in a ferrite matrix (Figure 10a) in both transverse and longitudinal section. The grains are elongated in all along the surface of the wire in longitudinal section (Figure 10b).

Visual Magnification 400X , Micro Photograph 2X180 Magnification.

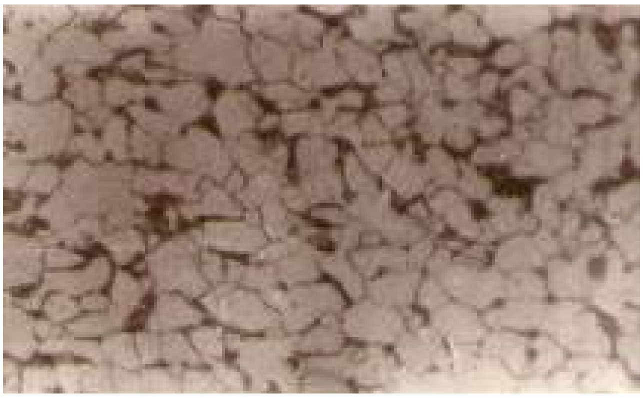

Figure 10a: Normalize structure 400X

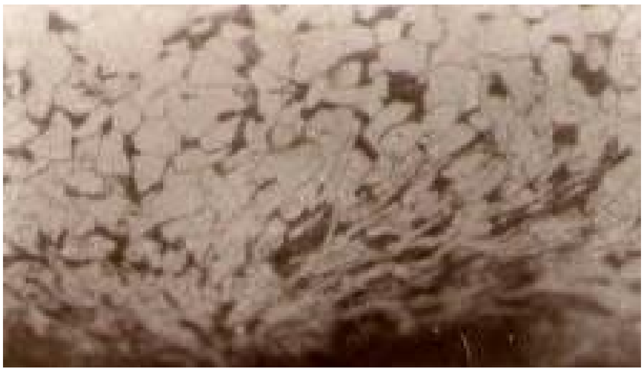

Figure 10b: Elongated grains 400X

F. Chemical analysis:

Table II: Chemical analysis of the guide rope

Element	% of Element	REMARKS
Carbon	0.16	As per IS: 1835-1976 for round steel wire for rope, the % of element should be as under : Carbon : 0.35 to 1.0 Manganese: 0.30 to 0.90 Silicon: 0.10 to 0.30 Sulphur & Phosphorus acceptable within point range P+S= 0.08, Max.
Manganese	0.48	
Silicon	0.106	
Sulphur	0.018	
Phosphorus	0.023	

G.Results & Conclusion:

1. From physical appearance of the fracture end which is a family of cup & cone shaped structure indicative of tensile failure.
2. Due to high reduction in diameter (57.44%) taken from all single broken wires, may have caused failure by tensile load causing fracture which exceeded the breaking load.
3. Further the micro-examination of the fracture end and bottom end revealed normalized structure with elongated grain indicative of stress on the wires of the rope.
   Poor lubrication at the broken end of the guide rope may leads to intermittent friction of wires forming nicks prone to corrosion of the wires.
4. The chemical (carbon content) composition was below the standard requirement.

VII. CASE STUDY – II:

Failure analysis of a winding rope used in coal mines:

A. Sample Description:

The failed sample of 25mm diameter and 6x7(6/1) construction FMC wire ropes from Dobari Colliery of 2 pit south side have been received to evaluate the causes of failure. Sample in two pieces were taken to investigate the cause of failure [8].

1. Fracture end
2. Fresh end

The Photographs of the samples are as under.

Figure 7: upper one – Fresh piece, Lower one - Broken end

Figure 8: Fracture Rope Samples showing broken surfaces

Figure 9: Fresh piece of rope

From the above figures it is clear that fibre core of the rope has come-out of the fracture end. The fracture end of the rope was badly damaged. The causes of the failure can be detailed out from the following Metallurgical examination.

B. Macro examination/ Visual examination:

A. Strand 1:

One wire of the strand has also been broken from the middle apart from the normal fracture of all the seven wires. The lay length was 172mm (Figure 10)

Figure 10: Broken wire of strand 1

Types of fractures are: two wires of conical tensile failure and five wires of Corrosion fatigue failure (Figure 10a).

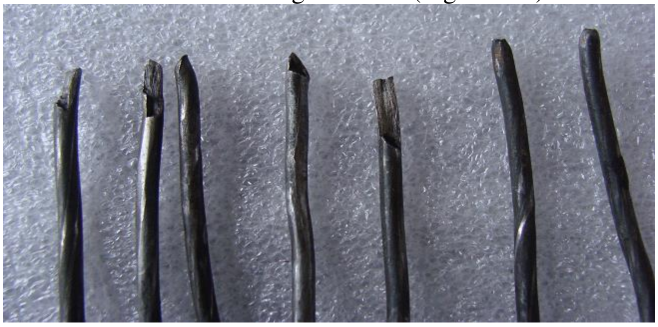

Figure 10a: Types of fracture of strand 1

Strand 2:

This strand was elongated and becomes straight having longest lay length among all of 220mm. The nature of fractures comprises of out of 7 wires, 5 wire of conical tensile failure and 2 wires of corrosion fatigue failure (Figure 10b).

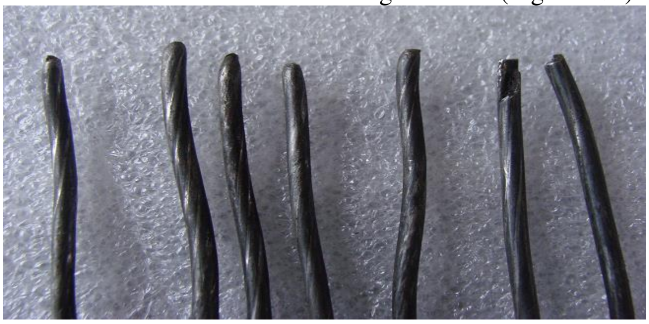

Figure 10b: Types of fracture of strand 2

Strand 3:

Two wires shows old fracture below its fracture end. The lay length of the strand was 180mm. The natures of fracture revealed out of 7 wires, 5 wires of corrosion fatigue failure and 2 wires of crystalline failure on full section wire (Figure 10C).

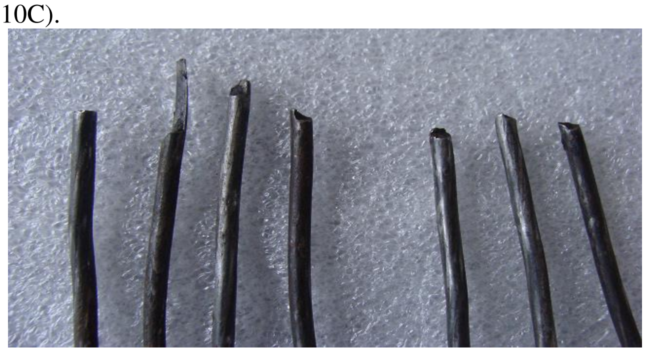

Figure 10C: Types of fracture of strand 3

Strand 4:

This strand shows 5 old fractures out of 7 wires below its fracture end. The lay length of the strand was 180mm. The natures of fractures are: 2 wire of conical tensile failure and 5 wire of corrosion fatigue failure (Figure 10d).

Figure 10d: Types of fracture of strand 4

Strand 5:

This strand revealed 1 wire has crack near the fracture end out of 7 wires. The lay length of the strand was 185mm. The Nature of fractures are, 2 wire of conical tensile failure, 2 wires of crystalline failure on full section of wire and 3 wire of corrosion fatigue failure Figure 10(e-I), Figure 10(e-II) & Figure 10(e-III).

Figure 10(e-I): Types of fracture of strand 5

Figure 10 (e-II): Types of fracture of Strand 5 with one wire broken from the middle

Figure 10(e-III): Types of fracture of Strand 5

Strand 6:

This strand shows tensile bending. The lay length of the strand was 173mm. The natures of fractures are: 1 wire of martensitic failure with fatigue crack developed and 6 wires of fatigue failure (Figure 11).

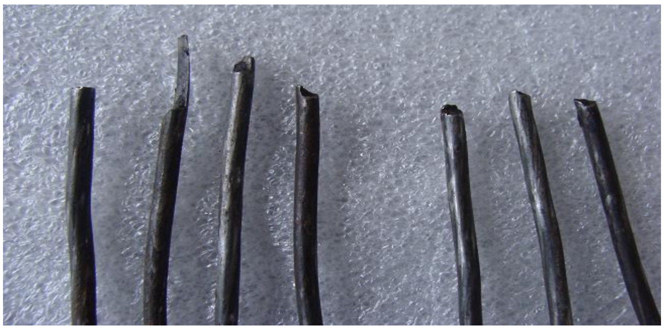

Figure 11: Types of fracture of strand 6

Nature of fracture of transverse section in broken ends: (Figure 11a)

Figure 11a: Types of fracture of strand 6

The above Figures indicate the Conical tensile and fatigue failure fracture of the rope and no. 2 Strand showed elongated i.e. lay length revealing the action of the heavy load on the particular strand.

C. Examination of wear & corrosion:

1) Broken rope:

The galvanized round steel rope wire sample on physical examination revealed abrasive wear, helical indentation marks, nicks and corrosion pittings on the surface of the wire.

Percentage reduction in diameter: 10.48%

2) Fresh rope:

The galvanized round steel rope wire sample on physical examination revealed abrasive wear, helical indentation marks and corrosion pittings on the surface of the wire.

Percentage reduction in diameter: 7.11%

D. Lubrication content in FMC wire rope:

3) Broken end:

Retention of lubricant in fibre Main core

Percentage retention of lubricant in FMC = 6.43 %.

The lubrication condition of the wire rope has been examined as per IS: 6594-1977. The Lubrication condition was very poor and found dry also.

4) Fresh rope:

Retention of lubricant in fibre Main core

Percentage retention of lubricant in FMC = 9.17 %.

The lubrication condition of the wire rope has been examined as per IS: 6594-1977. The Lubrication condition does not confirm to IS: 6594-1977.

E. Micro-examination:

5) Broken end:

The broken sample after cutting, grinding and polishing was examined under the microscope in an un-etched condition. The sample revealed no harmful inclusion as per IS: 4163-1982.

After etching in 1% nital solution the transverse section revealed uniform distribution of sorbitic pearlitic structure Figure 12a and the longitudinal section revealed good cold drawn structure Figure 12b of high carbon steel with peripheral damage of zinc coating & corrosion pittings Figure 12c and Microstructure also reveals structural displacement towards the tensile loading Figure 12d.

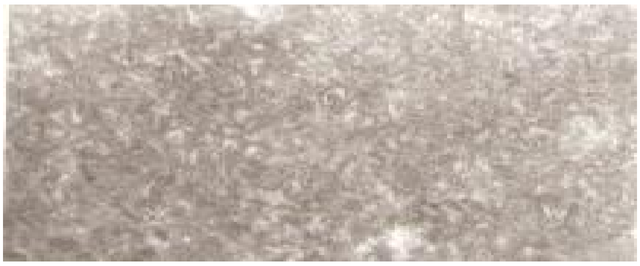

Figure 12a: Sorbitic - pearlitic structure in transverse Section

Figure12b: Good cold drawn structure in longitudinal section

Figure 12c: Corrosion pittings in longitudinal section

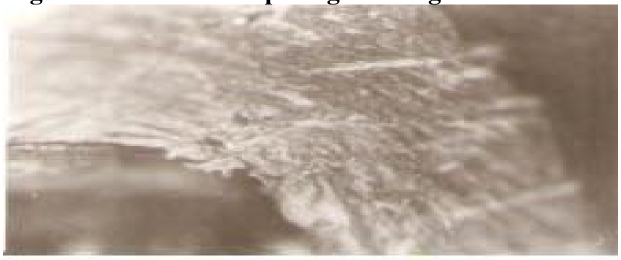

Figure 12d: Corrosion Pittings in longitudinal section

F. Chemical analysis (in percentage):

Table III: Chemical analysis of the broken end of the rope

Element	% of Element	REMARKS
Carbon	0.799	As per IS: 1835-1976 for round steel wire for rope, the % of element should be as under :
Manganese	0.67	Carbon : 0.35 to 1.0
Silicon	0.186	Manganese: 0.30 to 0.90
Sulphur	0.028	Silicon: 0.10 to 0.30
Phosphorus	0.032	Sulphur & Phosphorus acceptable within point range P+S= 0.08, Max.

G.Analysis of the result and conclusion:

1. From physical appearance of the fracture end, it seems that the failure was primarily from tensile bending stress.
2. Percentage reduction in wires diameter of broken ends was found to be 10.48%.
3. Percentage absorption of lubrication in the broken sample was found to be 6.43 %.
4. Chemical analysis of the broken sample was confirming to the standards IS 1863-1976.
5. Micro-examination revealed a good cold drawn structure except little corrosion pitting of the steel wire rope. The grain distortion due to tensile bending failure has also been absorbed.

It appears from the analyses result that the load on the rope exceeded from the normal breaking strength of the wire rope during operation. One strand of the rope was fully elongated during operation. Its poor lubrication in the wire rope aggravated the failure. However the rope was in good condition and the breaking load was also within the range of the rope. It seems sudden impact load was imparted on the rope exceeding the breaking load of rope caused failure.

VIII. CONCLUSION:

Corrosion is a natural phenomenon which deteriorates the industrial establishment and has a negative impact on economic growth of any developed or developing country. Further it poses a serious safety threat due to sudden failure of industrial appliances. From the above two case studies it is found that the static guide rope used in coal mines has been failed due to excessive corrosion resulted in high reduction in diameter (57.44%) leds to fracture due to tensile load. The poor lubrication at the broken end of the guide rope leads to intermittent friction of wires forming nicks prone to corrosion of the wires. Further, the chemical (carbon content) composition was below the standard requirement. On the other hand the moving winding rope, the failure was primarily from tensile bending stress. Micro-examination revealed a good cold drawn structure except little corrosion pitting of the steel wire rope. Its poor lubrication condition along with sudden impact load in the wire rope caused the failure.

It can also inferred that static ropes (suspension ropes or rope sections lying over a saddle or an equalizer sheave) are more likely to corrode faster than running ropes/ winding ropes.

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REFERENCE:

[1] ASM International.Corrosion: Understanding the Basics (#06691G), 2000
[2] Behrens. Br. Corrosion Journal, Vol. 10, Issue 3, p 122, 1967.
[3] Bineet Kumar Singh, Munmun Basak, Martin West, Indranil Guha; "Estimating the Cost of Corrosion in Indian industry", Petrotech-2010.
[4] Jaynil Gunarkar, "Wire rope, Chapter-5", Feb 06, 2013.
[5] Australian wire rope works Pty. Ltd.
[6] R. P. Singh, Mousumi Mallick, M. K. Verma & B. Ravi Kumar, "Studies on metallurgical properties of wire rope for safe operation in mines" Journal of Mines, Metals & Fuels, VOl.59, No.8,PP224-29, August 2011.
[7] CIMFR report "Study and failure analysis of 32mm diameter guide rope of K.B. 10/12 pits colliery, B.C.C.L, Dhanbad, Jharkhand" October 15.
[8] CIMFR report "Study the causes of failure of 25mm diameter winding rope used for winding at Dobari Colliery, Bastacolla area, B.C.C.L., Dhanbad" October 15

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